

## **Non-Invasive Measurement of Fluid/Gas Characteristics in Harsh Environments**

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Description:

**TECHNOLOGY AREA(S):** Ground/Sea Vehicles, Sensors

**ACQUISITION PROGRAM:** Strategic Systems Programs (SSP), ACAT I

**OBJECTIVE:** Develop and validate a portable, non-invasive sensor suite and post-processing capability that will accurately measure spatially resolved, time-dependent pressure, temperature, void-fraction, and velocity data within a multi-species, highly turbulent, supersonic flow through a short, thick-wall, curved steel pipe, without any element of the sensor suite permanently altering or physically crossing the pipe boundary.

**DESCRIPTION:** A novel approach to collecting flow performance data (i.e., pressure, temperature, density, voidfraction, and velocity) is needed to support routine performance assessments of Navy

hardware systems and needs to be demonstrated in a test environment. To minimize the high cost and safety impacts associated with hardware modifications and test conduct, a portable, non-invasive sensor suite is needed. The non-invasive sensors must collect data by instrumenting the outer surface of a pipe. Permanent modifications to the pipe structure are prohibited due to safety, cost, and logistical concerns. Legacy data do not provide the level of understanding desired to assess system performance and to support validation and eventual use of newly developed computational fluid dynamics (CFD) based modeling and simulation (M&S) tools because no solution currently exists to capture this data. New spatially resolved, time-dependent flow data will provide an improved understanding of the underlying physics within the flow phenomena, and also support flow performance assessments and predictions with the CFD M&S tools.

The current hardware under test consists of an upstream high pressure inlet mixing with a reservoir connected to a short, curved, thick steel pipe that flows the mixture of steam, water (from the reservoir), gas and pressure inlet by products into a larger chamber. The pipe is the area of measurement interest and is approximately 19-inches in diameter, has a 2-inch thick steel wall structure, contains one bend of less than 90 degrees and has an available straight pipe length of less than 5-inches. The environment to be measured during hardware tests is a high-pressure, high temperature mixture containing at least water/gas/steam created by igniting a double-based grain solid propellant (inlet pressure) into a water-filled reservoir. As the solid propellant expends itself, the mixture combines with propellant particulates. The noise generated by the solid propellant combusting has a broadband acoustic signature that is in the order of hundreds of decibels. The high-level, broadband acoustic noise environment may corrupt acquired data, particularly if the sensing method is ultrasonic in nature. The total duration, from ignition to propellant expended, lasts approximately 1 second.

The flow through the curved pipe can be characterized as multi-phase (i.e., water, steam, and propellant gases), compressible, nonhomogeneous, turbulent, and highly transient with the potential presence of shock waves within the pipe. During the ~1 s duration test event, the pressure in the pipe is expected to rise to ~600 psia; the temperature is expected to rise to ~400 °F; and flow is expected to have a mean motion velocity of ~800 ft/sec may exist.

Through industry searches, it has been determined that current commercially available technologies' response times and sampling rates are insufficient to non-invasively collect sufficient data. Additionally, any invasive sensor suite would be exposed to the harsh environments and would need to withstand the high temperatures, high velocities and high pressures. Historically, there have been difficulties with sensor survivability, which can result in loss of valuable data.

An innovative, non-invasive, prototype sensor is needed to obtain some, if not all, of the following short duration (~5 ms) time-average, spatial and temporal resolved data:

1. Pressure
2. Temperature
3. Density
4. Multi-phase void fraction (i.e., ratio of liquid to gas/steam/propellant mixture)
5. Velocity

**PHASE I:** Determine technical feasibility and develop a non-invasive, portable sensing system that can discern the presence of water, gas, and/or steam flowing within a 19-in. diameter, short (< 5-in. of straight length), curved, 2-in. thick steel pipe at flow speeds of up to 800 ft/s. Perform analysis, modeling and simulation, and/or laboratory investigations/demonstrations to provide initial assessment of approach. The size of the sensor suite is of less concern during the Phase I effort, as long as it is shown that the physical foot print of the sensor suite can be reduced in later phases.

**PHASE II:** Based on Phase I effort, further develop and demonstrate a non-invasive and portable sensing system that can measure and accurately quantify (to within 10%) the flow characteristics (i.e., pressure, temperature, density, void-fraction, and/or velocity) of a multi-phase fluid that is multi-species, compressible, and highly turbulent. This sensing system should be capable of being sized appropriately to fit within an approximately 3'x3'x3' volume. Performance of a demonstration to prove capabilities of the new system will be required. It can be expected that the government will provide the hardware under test in order to simulate the environment that needs to be measured.

**PHASE III DUAL USE APPLICATIONS:** The mature sensing system will transition into the program of record and will be used to assess system performance and to support validation and use of newly developed computational fluid dynamics (CFD) based modeling and simulation (M&S) tools. This technology and the data obtained from its use will be used on possible future programs as well.

**KEYWORDS:** Non-intrusive; sensor; multi-phase; supersonic; flow; instrumentation

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